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OPTIMALISATION THE POSITION OF SOLAR CELLS FOR VEHICLES

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An energy efficient solar power system and electric drive train has been developed with leadership of department of Automotive and Railway Engineering at Széchenyi István University in Gyor. This drive train with only solar power also has been successfully driven vehicle model for urban transport even in race conditions.

Under favorable sunny conditions the energy consumption of the electric motors is less than charge of the photovoltaic system. The system is operating at a positive energy balance.

The positive energy balance can be achieved with high-efficiency electric drive, which consists of two BLDC motors from Emoteq (MF 0210050) and an analog motor drive from Advanced Motion Controls (B40A8).

Two key elements of the solar driven system are maximizing solar electricity from the Sun and minimizing the drag coefficient of vehicle. The main aim of the current research is finding an optimum between these two factors.

The optimum placement of solar panels is the horizontal plane. The solar panels on top of the vehicle are parallel with the road plane. This is neither aesthetically correct nor is optimal from the aerodynamic point of view. The compromise of drag coefficient and irradiation conditions can be achieved by an optimization task. We can determine the two-way optimum curvature of the plane radiation and air resistance. The solution is a transparent streamline profile on the horizontal solar plane modules, which meets the requirements.

Keywords: energy of solar cells, energy management, electric vehicle, battery, MPPT, solar car, Shell Eco-marathon

Introduction

Regarding to the tendency of car industry nowadays, electrical powertrains will get more attention. Due to the low capacity of battery of this vehicles compared to the internal combustion engines, the efficiency is a main subject, what efficiency can the system transforms the electrical power to kinetic energy. In my essay I would like to optimize the providing and the usage of the electrical energy. We achieve the increase in the energy gathered from the sunlight with the optimization of the organization of the cells, the way of the connections and the charge controlling unit. We modified so the body to decrease drag.

We built a vehicle at the department of Automotive and Railway Engineering at Széchenyi István University in Gyor, what can lead us with its further development closer to our main aims.

The “SZEvolution car” built in 2010 under race circumstances have already showed its positive skills. At a nearly 30 km/h average speed we were able to charge more than we consumed. With this we were able to win the 2010 Shell Eco-marathon Solar Power Award in Urban Concept category.

The optimization of the vehicle’s efficiency with the reduction of the drag and increase of charging capacities the shape

According to aerodynamic calculations the body’s shape [1] that carries the solar cells is the best if is the shape of a drop. But with this shape the direction of sun lights is different on each cell. With cells connected in series the energy supplied by the circuit will be proportional with the smallest perpendicular component of the sun rays’ angle of incidence with the surface of the solar cells. It is likely that if the aim is to provide the most energy the solar cells’ direction is more important than the surface it is covering. In this case we can get the necessary charging circuit’s energy with a DC/DC converter.

With the optimal shape, we can not count with the power of all the cells, but the vehicle can be moved with less energy due to the decreased drag. With solar cells facing in the same direction we can achieve drag reduction by a transparent spoiler.

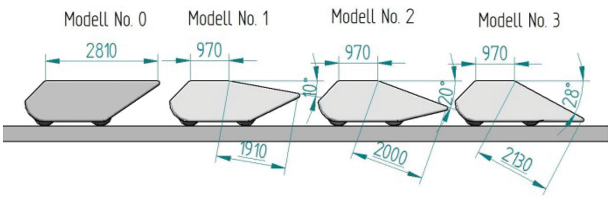

Figure 1: Details of the subject vehicle, in side view

During the combination of the two above discussed solutions we need to consider the connection of the solar circuits, because cells connected in line provide the current of the cell with the lowest value.

During the shape's, the charging capability's examination we must optimize the shape and the solar cell placement. At the designing of our car the average speed was an important point of view, due to that the shape specific drag force is proportional to the square of the speed.

Examining the effect of the drag

I was examining the side way view's shape. On *Fig. 1* the details of the car and the parameters of the modified rear end can be seen.

On *Fig. 2*, you can see the 3D model of the car, in this case a 20° draft was used at the rear end. At the edges a 50 mm fillet were applied.

The following four variations were examined. The 2010 vehicle is the base model (Model No.0), here the roof is one plane surface. At the first modification (Model No.1) the tail part has a 10° angle with the horizontal, at the second modification (Model No.2) this angle is 20° and at the third modification (Model No.3) it is 28°.

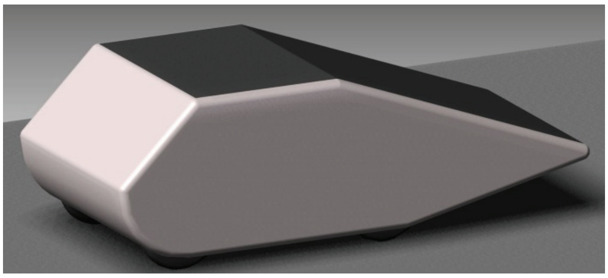

Figure 2: The 3D model of the car

Table 1: Drag forces, coefficient and the calculated performances at 8 m/s

Model types	Model No.0	Model No.1	Model No.2	Model No.3
Drag forces	Fl0	Fl1	Fl2	Fl3
(N)	28.17	22.24	19.37	20.78
Drag forces depending on the shape (c)	0.44	0.35	0.30	0.32
Performance loss due to the drag force	Pl0	Pl1	Pl2	Pl3
(W)	225.36	177.92	154.96	166.24

In these four cases the following air drag force and power values, as you can see in *Table 1*, were calculated with Solidworks Flow simulation.

The drag performances were calculated from the drag force multiplied by the speed (8m/s). The drag coefficient is in the fourth column [2]. With this we are able to calculate the drag performances of each speeds, they are shown extracted from the charging performances in *Fig. 7*.

On *Fig. 3* the performance loss due to the drag is shown at each examined models. It is clear to see that in the first three cases the drag force is decreasing with the increase of the angle. But at the last model the drag force is increasing as the shape is diverging from the optimal drop shape.

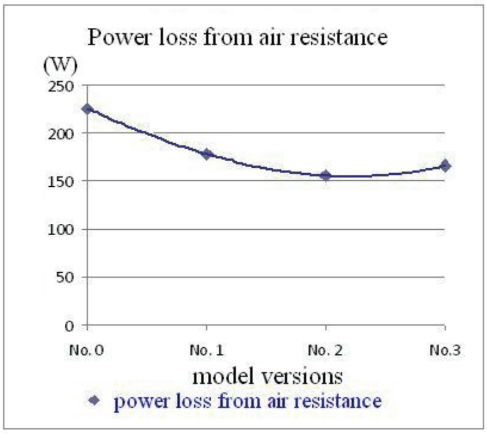

Figure 3: The change in the drag power of each model at 8 m/s

The changes in the charge power according to incidence of the sun rays angle

We are providing the maximum charging performance with a maximum power point tracking (MPPT) method [3]. At each solar circuit, the maximum power point is scanned with a micro processor system in the charging control unit that operates the solar circuit at these ideal circumstances.

With the in series connection of the solar circuit voltage of the solar cells are added. Connecting the circuits in line is useful only if they are facing in the same direction, so they are placed on one plane. In this case they can provide equal amount of energy, all of them can operate the same way. If there is a difference between orientations of the cells, the gathered current will be the current of the weakest cell. If more solar circuits are formed, than these are practical to design them to the same voltages. Because at parallel connected circuits they could worse each others power. Operating multiple solar circuits in different positions each circuit should be operated by separate charging control unit.

There are two factors that need to be kept in mind when placing and linking the cells. These are the solar ray angle of incidence [4] and the shape of the body.

At the following body shape I have calculated with an ideal solar cell linking. I have calculated the applicable solar cell performance proportional to the sun's angle of incidence. I ignored the losses of the connections, wirings and control units.

Under ideal circumstances the angle of the sun is perpendicular to the cells connected in line.

In the case of the top of the vehicle it is the best at noon, but also depends of the geological place of the vehicle. The amount of the direct current supplied by the solar cells is proportional to the smallest perpendicular component of the sun rays' angle of incidence.

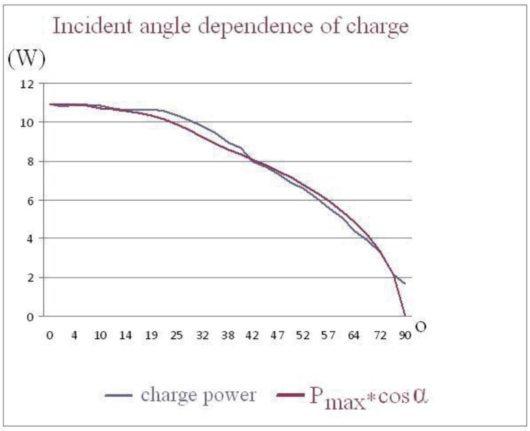

Figure 4: The measured and calculated performance of a cell

In the following measurement I have examined the effect of the light's angle to the charging performance. I have measured the maximum performances in case of fix light source, with the rotation of the solar cell module that consists of 4x2 cells connected in line.

The values *(Fig. 4)* are almost the same as the values provided by the producer of the cells.

The blue line shows the values that I measured; the red line is the maximal performance at 0°, multiplied by the perpendicular component of the angle of incidence due to rotation.

The two lines are almost the same, except at 90°, where the diffused light also effects the measurement.

From solar energy the solar cells placed on the vehicle providing electrical energy. The amount of the energy and performance that we can provide depends of the angle of incidence and the shape of the body.

In the following part I will parameterize the vehicle's charging performance calculating with an optimal charging arrangement.

I took the 2010 vehicle's size and shape for base (Fig. 1, Model no.0). At the examination of the cell's arrangement I have calculated only with the solar cells on the top.

The cells are on one plane, so we have to calculate with the perpendicular component of the sun rays. I marked the angle of incidence with γ and its values are the following from sunrise to sunset:

$$-90° \leq \gamma \leq +90°$$

The changing parameter of the vehicle during the optimizing is the angle of the top (α).

The more we lower the back of the car, the less the drag will be, but the gathered energy will be less. We have to search the maximal performance of the charger with the changing of α.

On Fig. 1, the 2010 car and the modifications are shown.

At the first modification the tail part has a α_1=10° angle with the horizontal, at the second modification this angle is α_2=20° and at the third modification it is α_3=28°.

With these modifications two plane surfaces can be covered with solar cells. Each solar cell used by our team has a 4.34 W ideal performance. With this value we can calculate that the top of the SZEvolution car (3.45 m^2) can provide maximum 616.5 W. From morning till dawn calculating with angles from -90° to +90° an average 370.6 W is estimated. On the following *(Fig. 5)* diagram the charging performances in connection with the angles of the light are shown. With modifications on the body, I got the values shown in *Table 2*. It is depending on the slope angle of the roof module to the models' average charging performance. It is shown in on *Fig. 6*.

Table 2: Average charge power of the measured models

Model types	Average charging performance	(W)
Modell No.0	Pchα=0	370.64
Modell No.1	Pchα=10	346.44
Modell No.2	Pchα=20	354.44
Modell No.3	Pchα=28	365.27

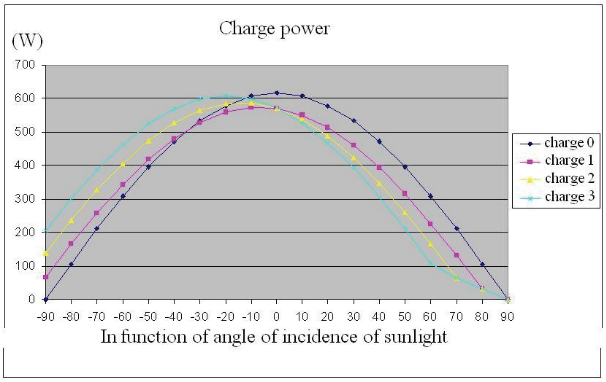

Figure 5: Charging power in function with the angles of the light

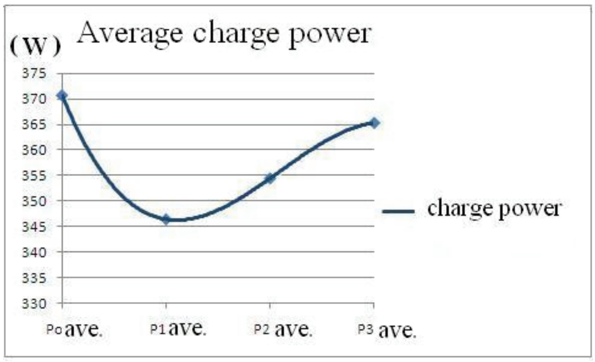

Figure 6: Average charging performance of the models

The charge of the first model is significantly worse than others. It is caused by the less applicable cells. In the last case it is almost as good as at model zero. It can be caused by the higher length of the top module, due to the increase of the angle, α. Meanwhile the drag also decrease, excepts the 3rd model.

Summary of the side view shape optimalization

At the tested models the tendency of the angle of the light's effect and the effect of the drag are seem to be the same.

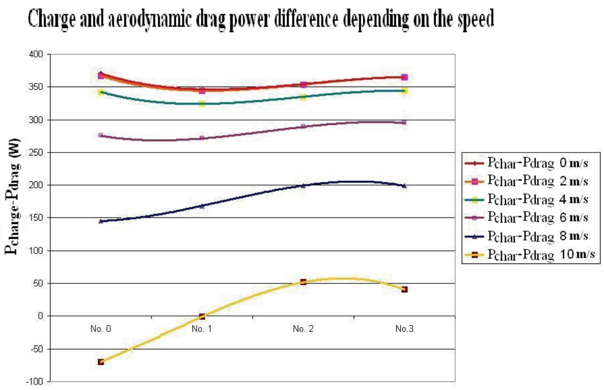

Figure 7: Difference between the charging performances of the models and the drag performances at different speeds

The energy used against the drag seems to decrease with lowering the tail, but the gathered energy seems to decrease with this modification, especially at low sun ray angles.

The difference between the charging power of the models and the drag power is shown on Fig. 7. If the speed is lower, the difference is the bigger. But at 10 m/s at some models we get negative values. So the charging performance is lower than the drag performance. At the race, the average speed is about 8 m/s so the models stay in the positive area.

Comparing the charging and drag powers the following statements can be set:

The charging performance is almost the twice of the drag performance (at 8 m/s).

The difference is shown on *Fig. 8*, with a red highlighted line. When this value is higher, than is better the shape according to energetically view. So it is shown that the model No.2 is the best according to my test measurements. Here the rear part of the vehicle has an angle of 20° with the horizontal.

The difference between the charging and drag performance is shown also on *Fig. 9*. I got the following values approaching with cubic equation. According to aerodynamic and charging views the ideal angle of the rear part is 23°.

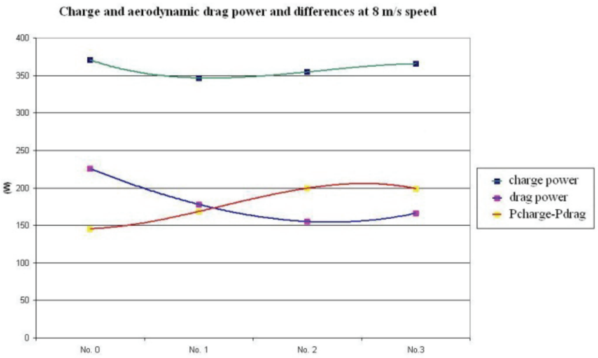

Figure 8: The effect of the shape to the charging and drag performance at 8m/s

Testing the way of connecting the solar cells

The ideal shape is the drop shape. If we would like to cover this surface we would have to use many small cells. Each would be facing in a different direction. To be able to connect all this cells into an optimal circuit, we would need a matrix network, with separate units measuring and controlling each cell. The costs and the weight of this system are not likely to be compensated by its benefits. In addition we would need lots of DC/DC converter to increase the charging circuits' voltage to the needed level. It would cause an additional 5–10% energy loss. That is, why I divided the roof into two plane surfaces. The drag is reduced by 35% and the loose in the charge is only 5%. Using the second model, moving with the average speed the total gained efficiency is +37%. This number is calculated from the aerodynamic components and the charging performances with ideal weather and solar cell linking.

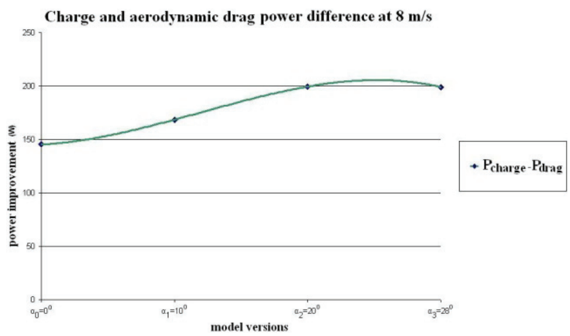

Figure 9: The changing of the difference between the charging and drag performance

We have developed our vehicle further by utilizing our experience and measuring results (6, 7) of the vehicles built in the previous years *(Fig. 10)*. Both electric charging system and the solar cells have been optimized. Charging performance of the vehicle has improved significantly, even under non-optimal weather conditions. As a result of the tests executed meanwhile, I expect further efficiency increase from the improvement of the MPPT system. Improvement of the air-drag coefficient does not reduce the charging power but results in lower energy consumption. By improving the cooling of the solar cells, we want to reduce the negative effects of the higher temperature, we expect at the date of the competition. Contrary to early May dates of the previous years, in 2011, the race will be held at the end of May.

Vehicle construction

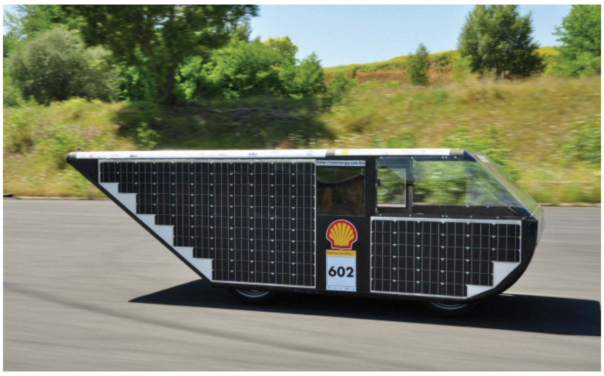

Figure 10: "SZEvolution car" built in 2010

Conclusion

Efficiency of electric-powered vehicles is extremely important. Its improvement results in increase of the driving distance that can be achieved with one charge. It is also our goal with the vehicles we develop for the Shell Eco-marathon. Through increase of the charged power and reduction of the consumption, an efficiency increase up to 10 percent can be achieved in comparison to the vehicle built in previous year.

For this result, it is necessary to optimize the shape of the vehicle from the air-drag and charging power points of view. Based on the evaluated models, it is to be concluded that energy conditions can be improved the most by using model No.2. With this shape, loss of power due to air-drag can be reduced with 35%. Meanwhile, charging power reduces with some 5%. Counting with an average racing speed, with the new shape a performance increase up to 37% could be achieved.

REFERENCES

1. www.static.shell.com/static/ecomarathon/downloads/2011/global/SEM_Rules_2011_Final.pdf
2. Á. ZOMOTOR: Gépjármű menetdinamika, Már-Más Bt, Budapest, pp. 20–32, 2004
3. C. A. GIRALDO-CASTAÑEDA, L. R. ORAMA: Selective Hopping Maximum Power Point Tracking Method for PV systems, ICSET, 522–526, 2008
4. C. SUNGUR: Multi-axes sun-tracking system with PLC control for photovoltaic panels in Turkey, Renewable Energy 34, (2009), 1119–1125
5. www.boschsolarenergy.com/fileadmin/downloads/Datenblaetter/_Bosch_Solar_Cell_M_3BB_englisch.pdf
6. I. SCHMIDT, I. RAJKI, GY. VINCZE: Járművillamosság, Műegyetemi Kiadó, Budapest, pp. 170–205, 2002
7. I. EMŐD, Z. TÖLGYESI, M. ZÖLDY: Alternatív járműhajtások, Maróti Könyvkereskedés és Könyvkiadó Kft, Budapest, pp. 101–127, 2006